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Fluctuations of Selected Agrometeorological Indices in Wielkopolska in years 1966-2005

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1. Introduction

Presently observed climate changes naturally arouse eager interest in the study of time series of climate elements. This interest is especially high in those economic fields that are particularly vulnerable to weather conditions such as agriculture. This paper presents the analysis of changes of some of climate elements that have a direct impact on agricultural production, i.e. moisture supply for crops.

The majority of climatic elements and calculated on their basis agrometeorological indices display fluctuations in time. These fluctuations are characterized by sequenced tendencies where relatively high values are followed by relatively low values in time series. Examination of fluctuations gives information on the actual direction of the observed changes and may also be the starting point for research on future trends.

2. Area of research

The paper discusses the area of Wielkopolska Voivodship, which is almost identical in size and shape to the Wielkopolska physico-geographical region. Wielkopolska Voivodship is located in the central-west Poland (Fig.1). The area covers ca. 30,000 km², with the population of ca. 3.4 mln. The highest elevation is located in the south of the region (264 meters), and the lowest point - in the north-western part (25 meters).

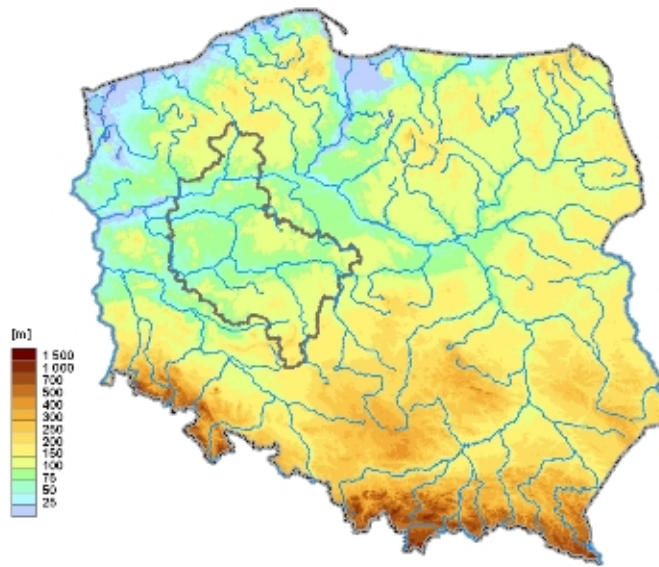


Fig. 1
Wielkopolska region in Poland

Wielkopolska Region is located in the moderate climate zone with significant influence of oceanic climate whose effects decrease towards the east. Compared to other Polish regions, Wielkopolska is characterized by a relatively early offset of spring and summer and a rather short winter. The mean annual air temperature is ca. 8.0 C°, with the extremes of +38° C and -29° C. The growing season lasts ca. 220 days and is one of the longest growing season in Poland. Snow cover lasts ca. 40 days. Precipitation values are low and with high temporal variability. The mean annual precipitation totals are the highest in the western parts amounting to 550 mm with decreasing tendency toward the east where they drop locally below 500 mm. Summers are characterized by quite frequent occurrences of periods with no or little rain lasting up to several weeks. Rain deficits cause development of atmospheric drought followed by soil moisture loss and hydrological drought. Despite these conditions the agriculture in Wielkopolska is very well developed in comparison to other regions of Poland.

3. Data

In the study the standard meteorological measurement data were analyzed. The data were collected by 14 synoptic stations located within the borders of Wielkopolska region and surrounding area (Fig. 2) in 1966-2005.

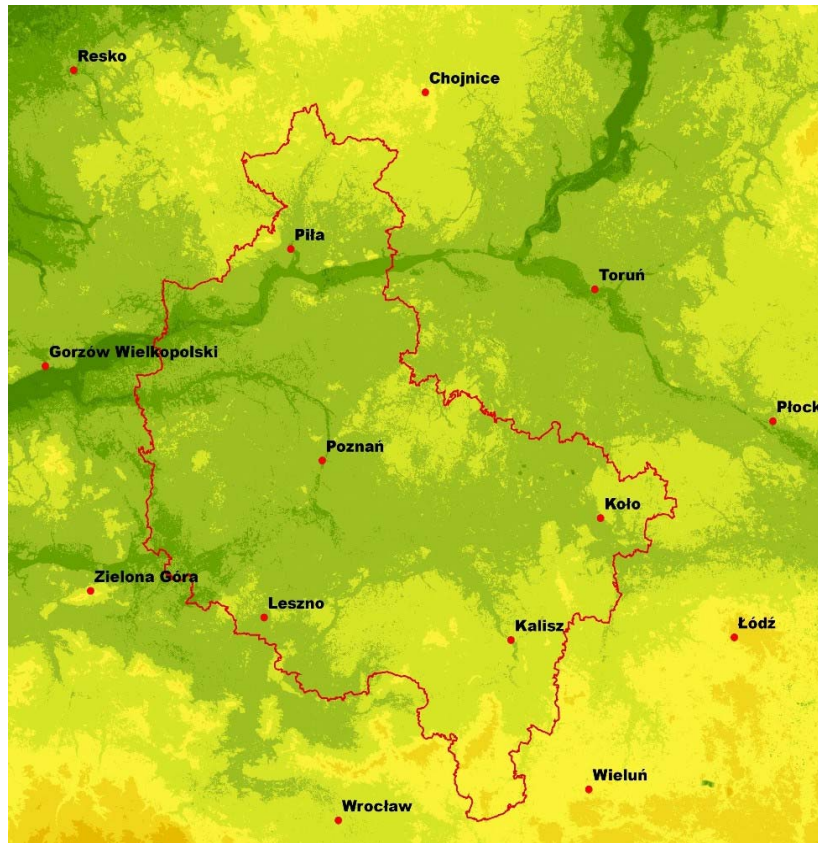


Fig. 2
Localization of the synoptic stations

4. Methods

Atmospheric precipitation deficit is one of the most serious effects of the climate changes threatening further development of agriculture in Wielkopolska. In order to investigate closer this problem, selected agroclimatic indices characterizing water availability for crops were analyzed. Agroclimatic indices were grouped as follows:

Indices characterizing water supply:

- atmospheric precipitation totals [mm] (1m above the ground)
- number of days with precipitation of ≥ 3 mm
- number of days with precipitation of ≥ 20 mm

Indices determining water losses:

- mean air temperature [$^{\circ}$ C] (2m above the ground)
- number of hot days ($T_{\max} \geq 25^{\circ}$ C)
- number of extremely hot days ($T_{\max} \geq 30^{\circ}$ C)
- sunshine hours [h] (ca. 5 m above the ground level)
- evaporation [mm]
- climatic water balance (CWB) [mm].

The group of indices characterizing water supply includes two indices describing number of days with atmospheric precipitation. Two threshold values of precipitation were adopted: 3 mm and 20 mm. The selection of these two values was dictated by the fact that they are related directly to vegetative conditions of the crops. Many researchers assume that in Polish conditions diurnal precipitation of 3 mm puts an end to period without rain (rain reaches soil surface through plants during vegetative period), while precipitation of ≥ 20 mm may cause crop losses and diminishes effectiveness of agrotechnical measures.

Index that “summarizes” fluctuations of agrometeorological indices included in this paper is climatic water balance. Negative values of climactic water balance are referred to as climatic water deficit or atmospheric precipitation deficit.

Climactic water balance (CWB) is calculated using the following equation:

$$CWB = P - E$$

where:

CWB – climactic water balance [mm],

P – atmospheric precipitation [mm],

E – evaporation [mm].

The following data were used in CWB calculation:

- monthly precipitation totals,

- monthly evaporation totals calculated as indicatory evaporation with the Bac's equation¹:

$$E = 3d\sqrt{v} + 4Q$$

where:

E – indicatory evaporation [mm], conventional value of the maximum possible evaporation from a given surface with constant water saturation,

d - mean value of air humidity deficiency [hPa] at the altitude of 2 m, i.e. value characterizing atmosphere potential to absorb water vapor,

v - average wind speed [m/s] at the altitude of 10 m, indicating exchange rate between air saturated with water vapor and less saturated air,

Q – monthly solar radiation total [kcal] characterizing the amount of thermal energy reaching the surface calculated with Black's equation.

Data collected in 1966-2005 was the basis of the analysis. Agrometeorological indices in vegetative period (Apr.-Sept.) of each particular year of the 40-year period were either totaled or averaged.

One of the methods used for fluctuation analysis is the method of moving average. The method of moving average, used to characterize multi-year changes of climatic elements, is superior to the often used method of regression analysis in that it does not impose a presumed function that approximates the actual run of the examined variable. The result of this method is only “smoothing” of fluctuations in period shorter than the corresponding set of the averaged data. The selection of set of the averaged data was determined by the fact that the aim of this research was to find out what the main directions of the actual changes are while omitting frequent few year fluctuations, and also by the fact that relatively short data

¹ Bac is a Polish researcher who introduced equation for calculation of evaporation based on long term field measurements.

It was tested and is now used by many researchers to describe climate and agroclimate conditions in Poland.

sets were used, i.e. 40-year time series. Based on the results, 15 years data subsets were taken for averaging values of calculated indices. The sets of agrometeorological indices were analyzed using 15-year moving averages which were then examined for deviations from 40-year average. These deviations show main characteristics of variability of examined indices in 1966-2005.

In case of each analyzed index, the period of the highest and the lowest value of the 15-year average for each station was noted. Statistical significance of differences between the extreme average values was analyzed using Student's t-test at the significance level of $\alpha=0.10$ and 0.05

Fluctuations were described in two 20-year sub-periods: 1966–1985 and 1986–2005. This was done not only for practical reasons but also due to the fact that the second subperiod showed a considerable air temperature increasing trend. The first 20-year period, therefore, can be seen as a reference or base period for determination of changes observed during the years 1986-2005.

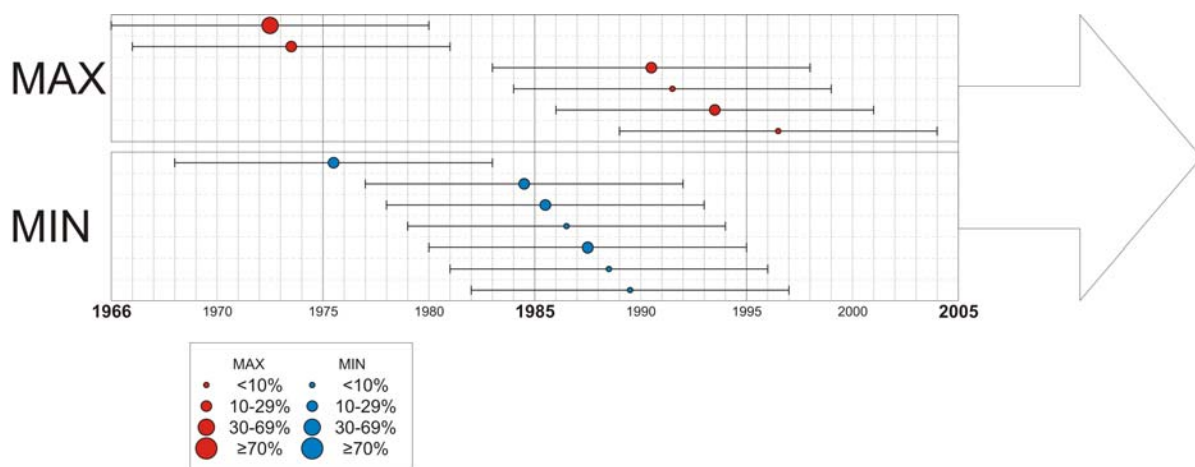
5. Results

Indices characterizing water supply

Precipitation totals [mm]

Variability of atmospheric precipitation totals was different for each station.

Figure 3. Periods with the maximum and minimum values of mean 15-year precipitation totals during vegetative season



MAX (red dots) – highest values of 15-year average

MIN (blue dots) – lowest values of 15-year average

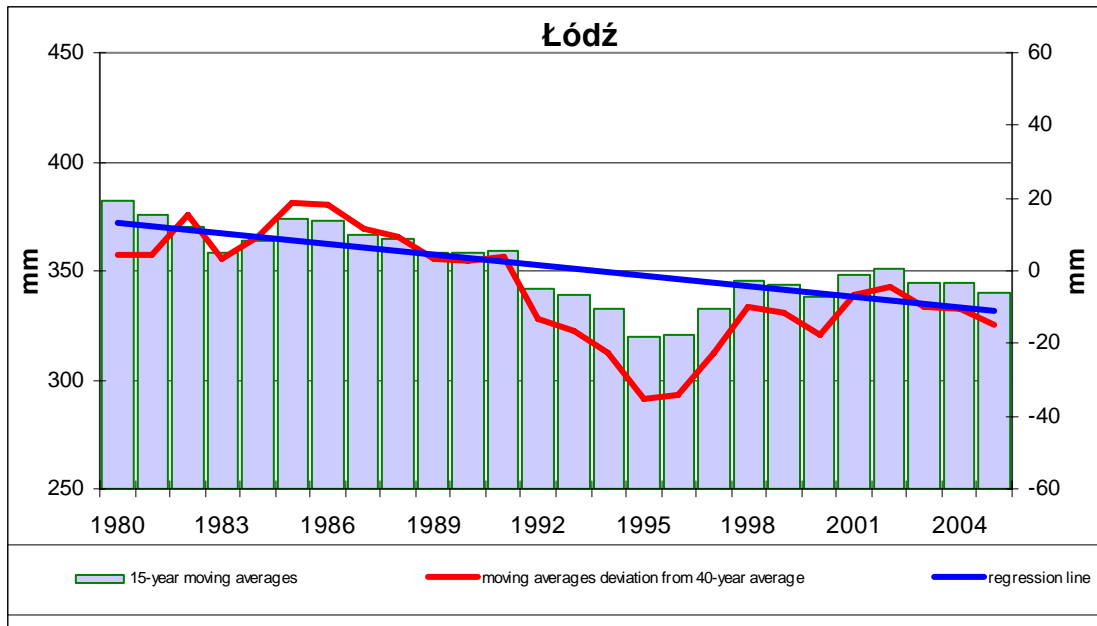
The size of red and blue dots corresponds to the number of stations (expressed in %) where given extreme value was recorded for each 15-year period.

Horizontal lines correspond to 15-year periods.

Data collected from the total of 14 stations.

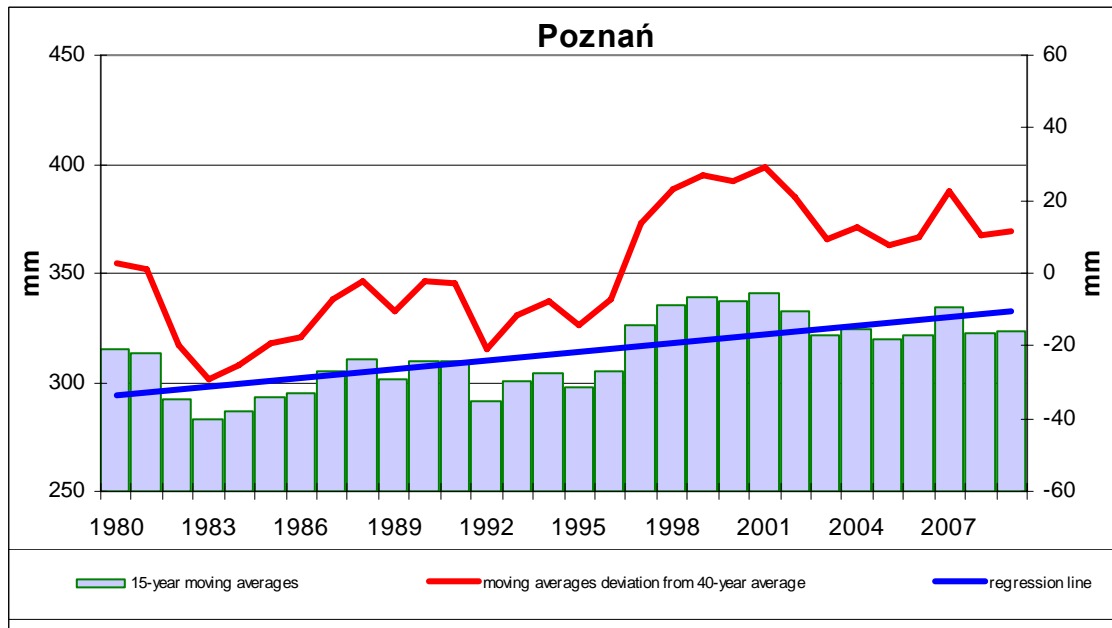
In the majority of cases (2/3 of the stations) high precipitation during vegetative period occurred in the beginning of the first 20-year period, in the middle or towards the end of the second 20-year period. In this group of stations, the minimum precipitation totals were recorded at the end of the first and the beginning of the second sub-period.

Figure 4. Precipitation totals fluctuations in 1966-2005. Łódź synoptic station.
 15-year average 1966-1980 is shown by 1980 bar and etc.



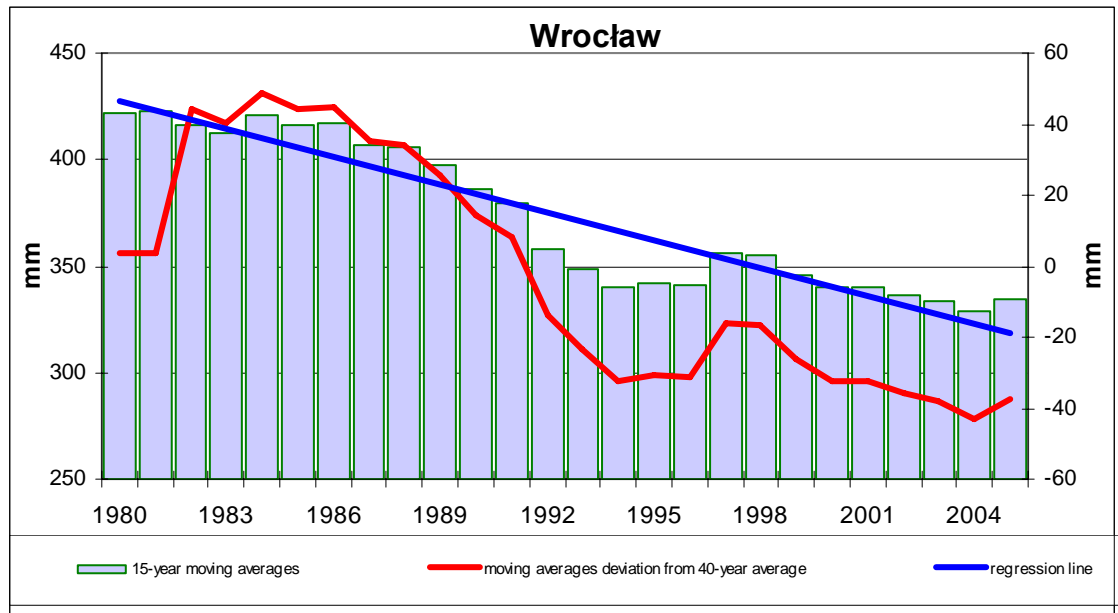
In case of almost 1/3 of the stations, moving average minima occurred at the beginning of the first 20-year period while the maxima occurred in the middle and in the end of the second 20-year period.

Figure 5. Precipitation totals fluctuations in 1966-2005. Poznań synoptic station.
 15-year average 1966-1980 is shown by 1980 bar and etc.



In case of one station (Wrocław), the whole 40-year period was dominated by a decreasing trend of precipitation totals.

Figure 6. Precipitation totals fluctuations in 1966-2005. Wrocław synoptic station.
15-year average 1966-1980 is shown by 1980 bar and etc.



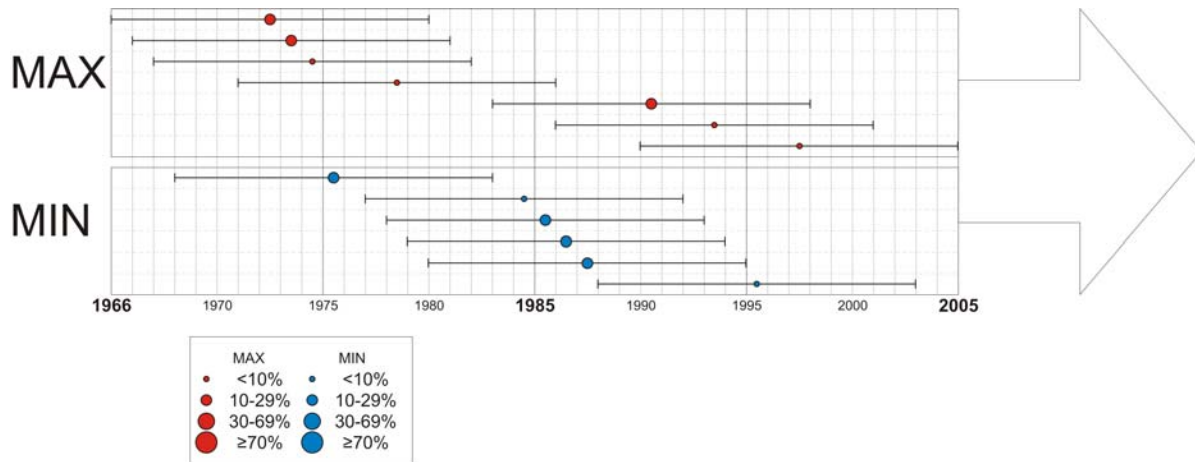
Regardless of the characteristic of precipitation during the 40-year period, 2/3 of all stations recorded decreasing trend of precipitation totals in the last few years of the second 20-year period.

The differences between the maximum and minimum average 15-year values had the significance level of $\alpha=0.05$ for 29% of all stations (localized in the south-east of the analyzed area), and the level of $\alpha=0.10$ for almost all the remaining stations.

Number of days with precipitation ≥ 3 mm

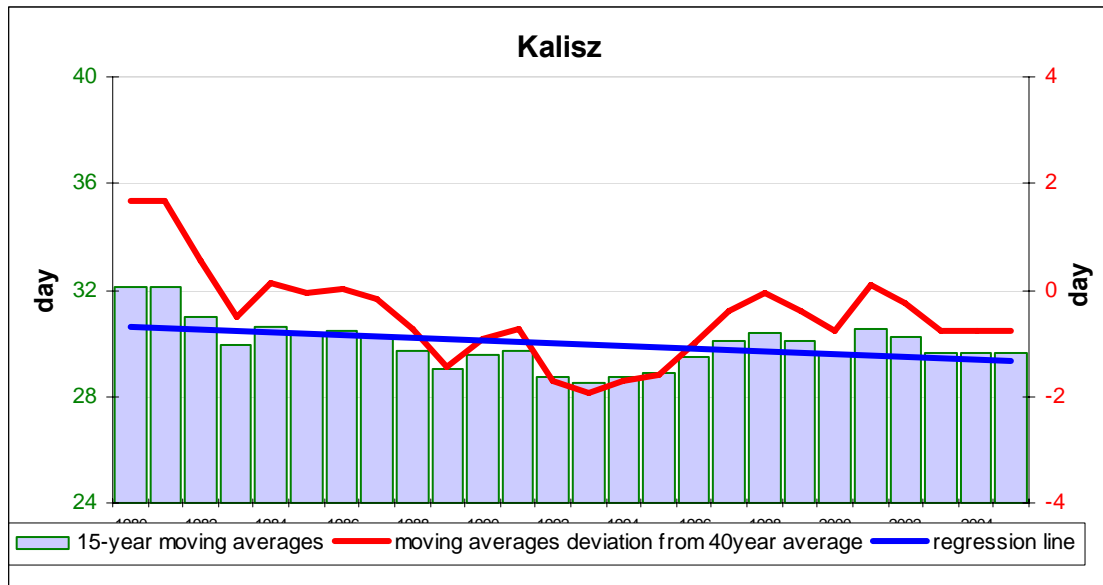
Fluctuations of number of days with precipitation ≥ 3 mm were different for each station, as it was the case with the previous index.

Figure 7. Periods with the maximum and minimum values of mean 15-year number of days with precipitation ≥ 3 mm during vegetative season



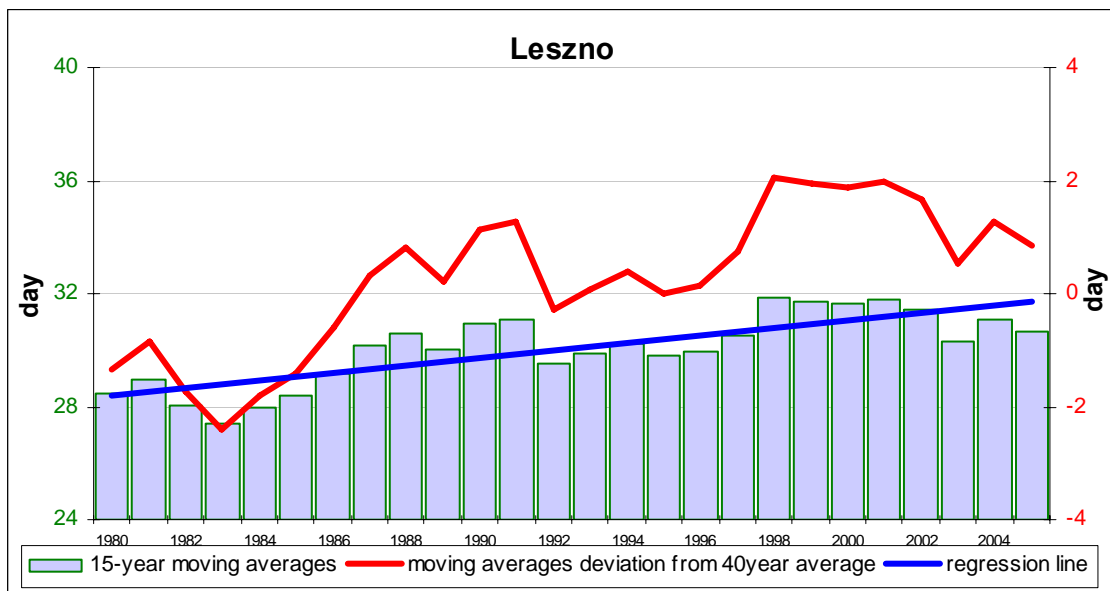
In the majority of cases (almost 2/3 of stations) high number of days with ≥ 3 mm precipitation occurred in the middle of the first 20-year period and again in the first half of the second period. In this group of stations, the minimum number of such days was most frequently recorded at the beginning of the second period.

**Figure 8. Number of days with precipitation ≥ 3 mm fluctuations in 1966-2005. Kalisz synoptic station.
15-year average 1966-1980 is shown by 1980 bar and etc.**



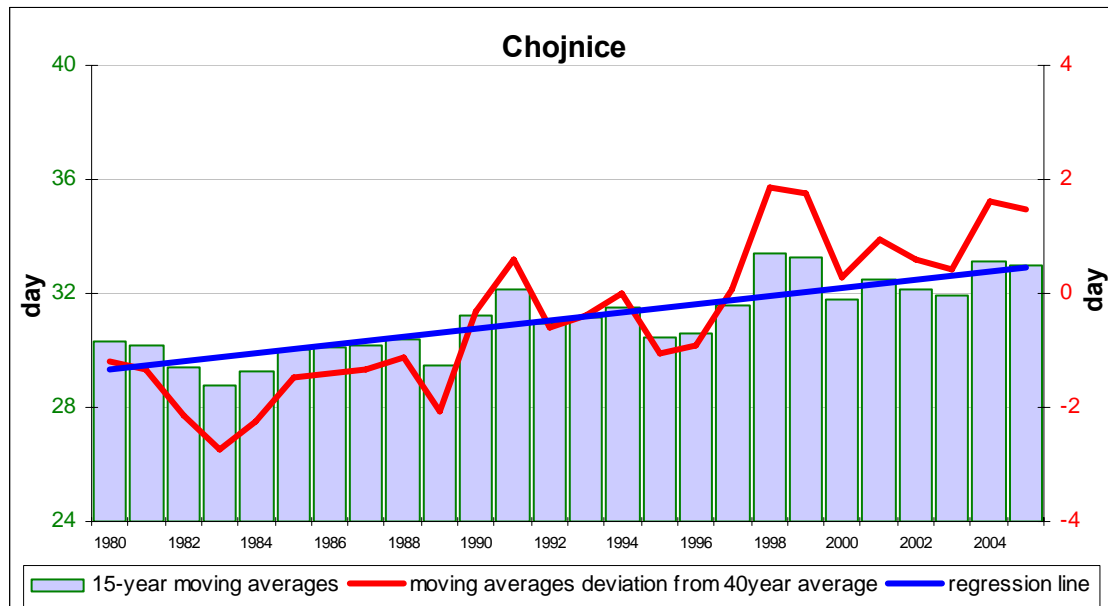
In case of almost 1/3 of the stations, moving average minima occurred in the middle of the first 20-year period and the maxima in the first decade of the second 20-year period.

**Figure 9. Number of days with precipitation ≥ 3 mm fluctuations in 1966-2005. Leszno synoptic station.
15-year average 1966-1980 is shown by 1980 bar and etc.**



One station (Chojnice) was dominated by the increasing trend of number of days with precipitation of ≥ 3 mm throughout the entire 40-year period.

Figure 10. Number of days with precipitation ≥ 3 mm fluctuations in 1966-2005. Chojnice synoptic station. 15-year average 1966-1980 is shown by 1980 bar and etc.

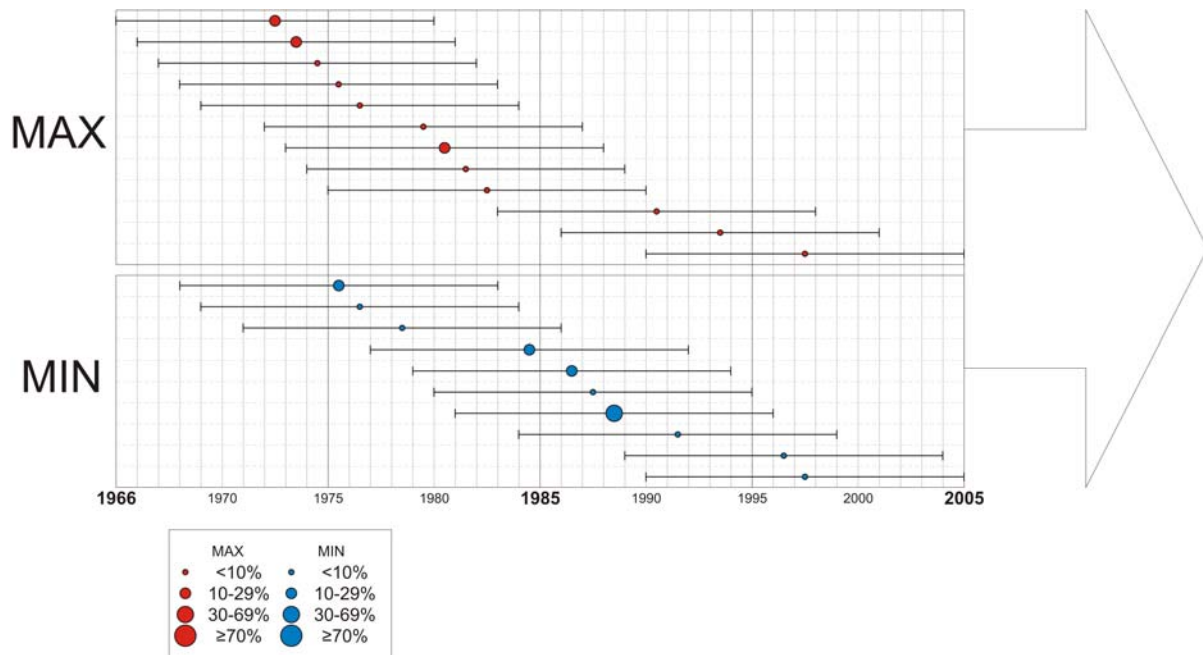


Regardless of the characteristic of precipitation during the 40-year period, 2/3 of all stations recorded decreasing trend of this index in the last few years of the second 20-year period. Differences between the maximum and minimum 15-year average values had significance value at the level of $\alpha=0.05$ for only one station, while for 2/3 of stations it was $\alpha=0.10$.

Number of days with precipitation of ≥ 20 mm

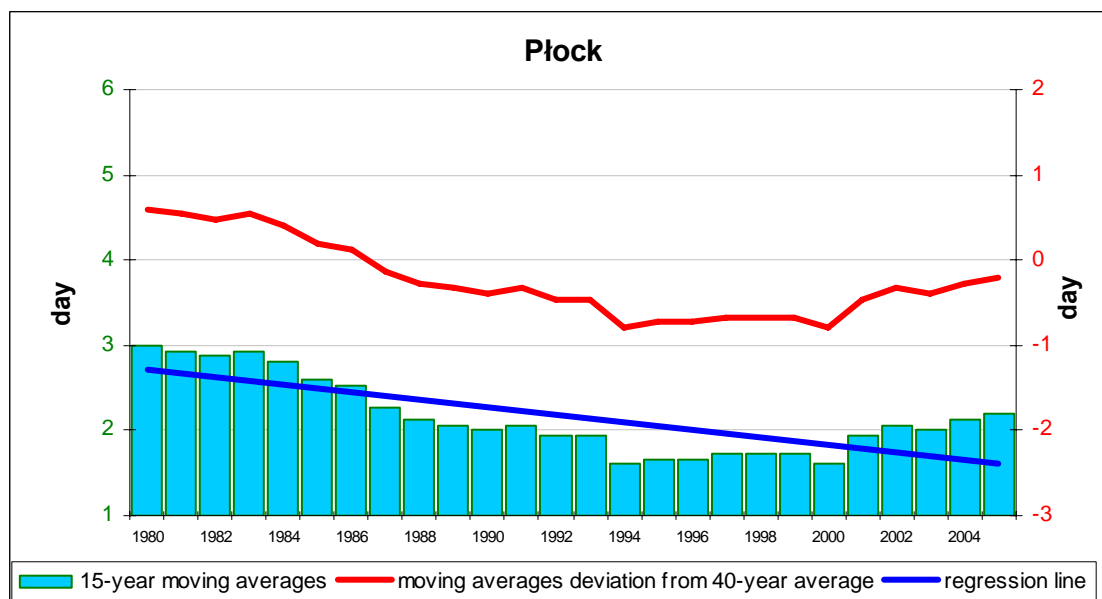
The run of fluctuations of number of days with precipitation of ≥ 20 mm was similar for the majority of stations.

Figure 11. Periods with the maximum and minimum values of mean 15-year number of days with precipitation ≥ 20 mm during vegetative season



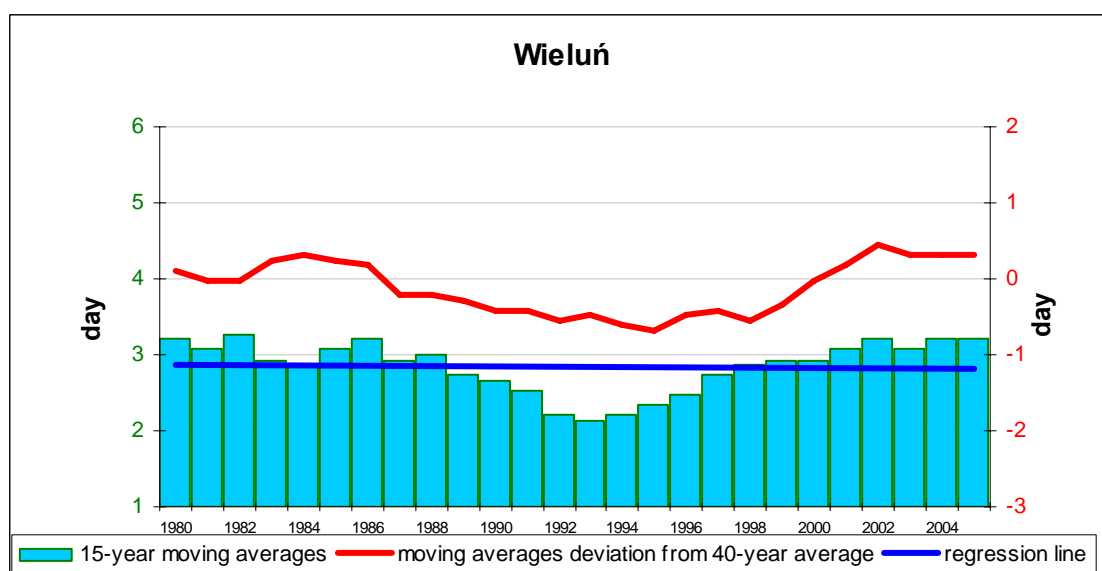
In most cases (over 2/3 of stations) moving average maxima occurred in the first 20-year period and minima in the end of the first and the beginning of the second sub-period. By the end of the analyzed 40-year period, the value of the analyzed index increased again.

Figure 12. Number of days with precipitation ≥ 20 mm fluctuations in 1966-2005. Plock synoptic station.
 15-year average 1966-1980 is shown by 1980 bar and etc.



86% of stations recorded an increase of number of days with precipitation of ≥ 20 mm in the second 20-year period. However, in the last years, half of the stations observed either termination of the increasing trend of number of days with precipitation of ≥ 20 mm or a decrease of number of such days.

Figure 13. Number of days with precipitation ≥ 20 mm fluctuations in 1966-2005. Wieluń synoptic station.
 15-year average 1966-1980 is shown by 1980 bar and etc.



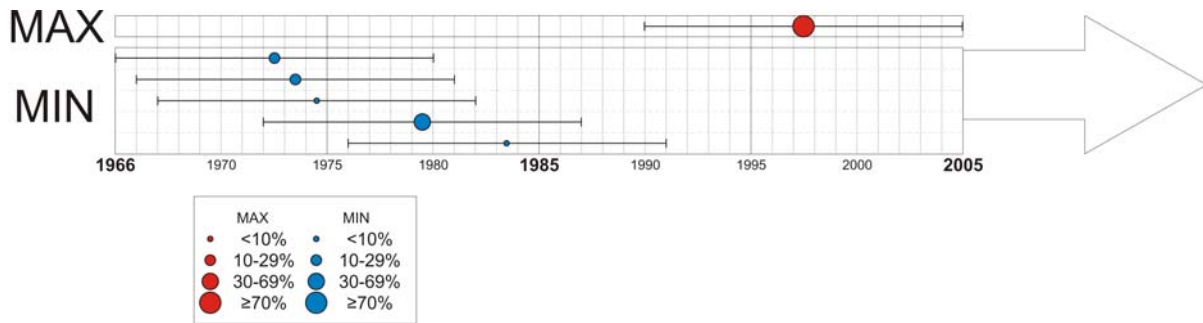
Differences between the maximum and minimum 15-year average values had significance value at the level of $\alpha=0.05$ for only one station, while for 1/3 of stations it was $\alpha=0.10$.

Indices characterizing water losses

Mean temperature [°C]

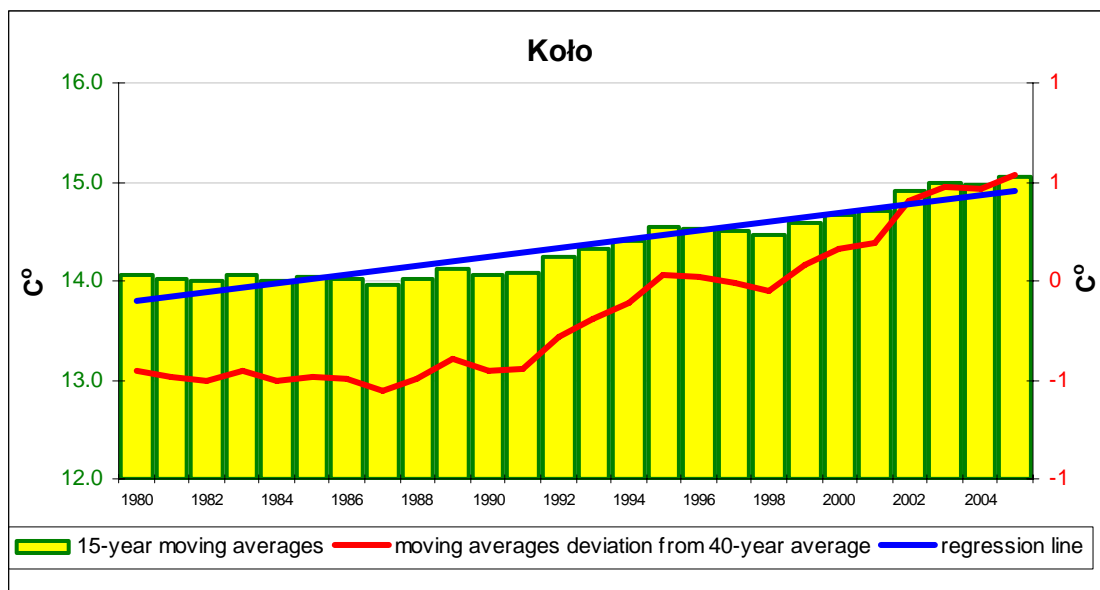
The run of mean air temperature was similar for all stations.

Figure 14. Periods with the maximum and minimum values of mean 15-year mean temperature during vegetative season



During the first 20-year period, negative temperature anomaly was noted in relation to the mean 40-year value. All minima of moving averages occurred here. The second 20-year period was characterized by a systematic increase of mean air temperature during vegetative period. The highest values of 15-year averages in all stations ended in 2005. Differences between the maximum and minimum 15-year average values in all stations (with one exception) had the significance value at the level of $\alpha=0.05$.

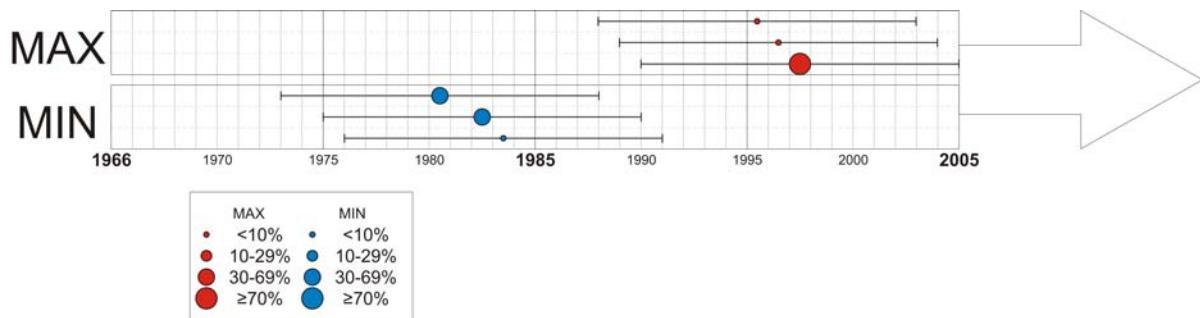
Figure 15. Mean temperature fluctuations in 1966-2005. Kolo synoptic station. 15-year average 1966-1980 is shown by 1980 bar and etc.



Number of days with $T_{max} \geq 25^{\circ}C$

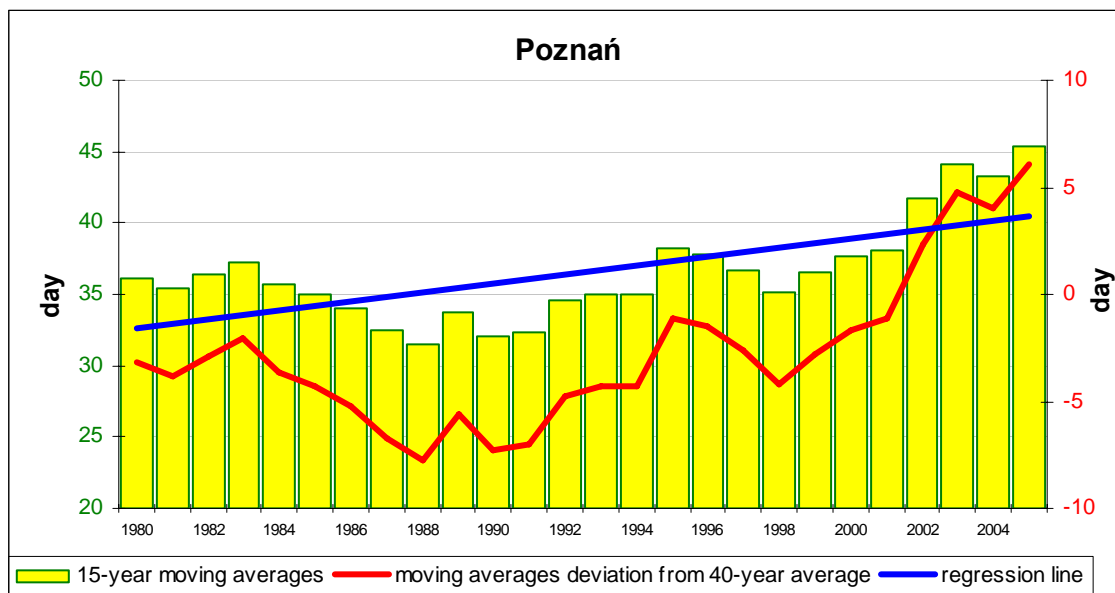
The run of fluctuations of the number of hot days was similar for all stations.

Figure 16. Periods with the maximum and minimum values of mean 15-year number of days with $T_{max} \geq 25^{\circ}C$ during vegetative season



The first two decades saw a slow decrease of number of such days, while in second period there was a visible increase of the number of hot days. All minimum values of moving averages occurred at the end of the first period and the beginning of the second period while maximum values occurred in the end of the second 20-year period. Differences between the maximum and minimum 15-year average values in all stations (with one exception) had the significance value at the level of $\alpha=0.05$.

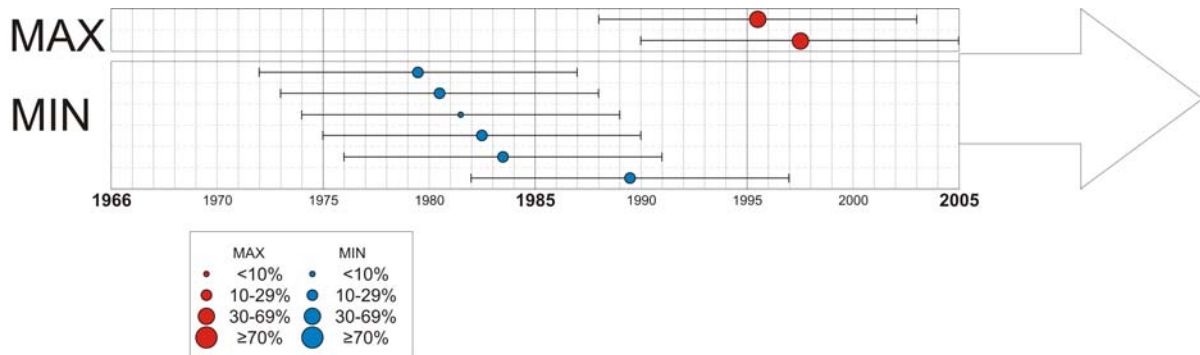
Figure 17. Number of days with $T_{max} \geq 25^{\circ}C$ fluctuations in 1966-2005. Poznań synoptic station. 15-year average 1966-1980 is shown by 1980 bar and etc.



Number of days with $T_{max} \geq 30^{\circ}C$

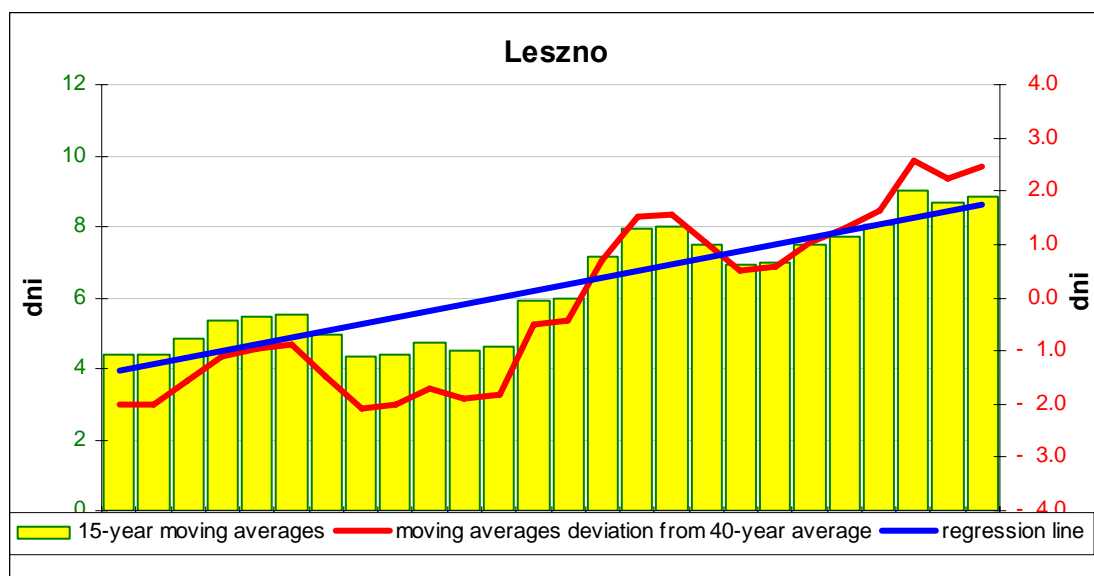
The run of variability of the number of extremely hot days was similar for all stations.

Figure 18. Periods with the maximum and minimum values of mean 15-year number of days with with $T_{max} \geq 30^{\circ}C$ during vegetative season



The first 20-year period was characterized by an increase followed by a decrease of the number of extremely hot days. The end of this period was characterized by minima showing in the run of moving averages for all stations (with a single exception). The second 20-year period experienced a visible increase of number of extremely hot days. Maxima of moving averages occurred in the last years of the second period. The differences between the maximum and minimum average of 15-year values had the significance level of $\alpha=0.05$ for 79% of stations, and the level of $\alpha=0.10$ for three stations located in the north-west of the analyzed area.

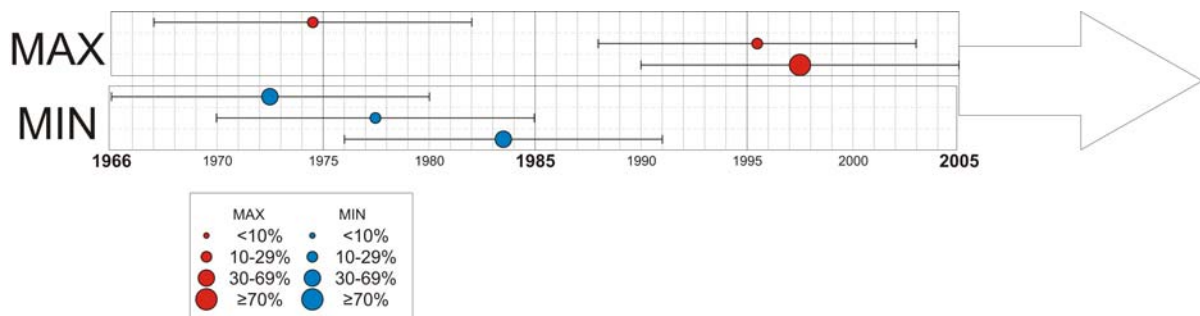
Figure 19. Number of days with $T_{max} \geq 30^{\circ}C$ fluctuations in 1966-2005. Leszno synoptic station. 15-year average 1966-1980 is shown by 1980 bar and etc.



Sunshine hours [h]

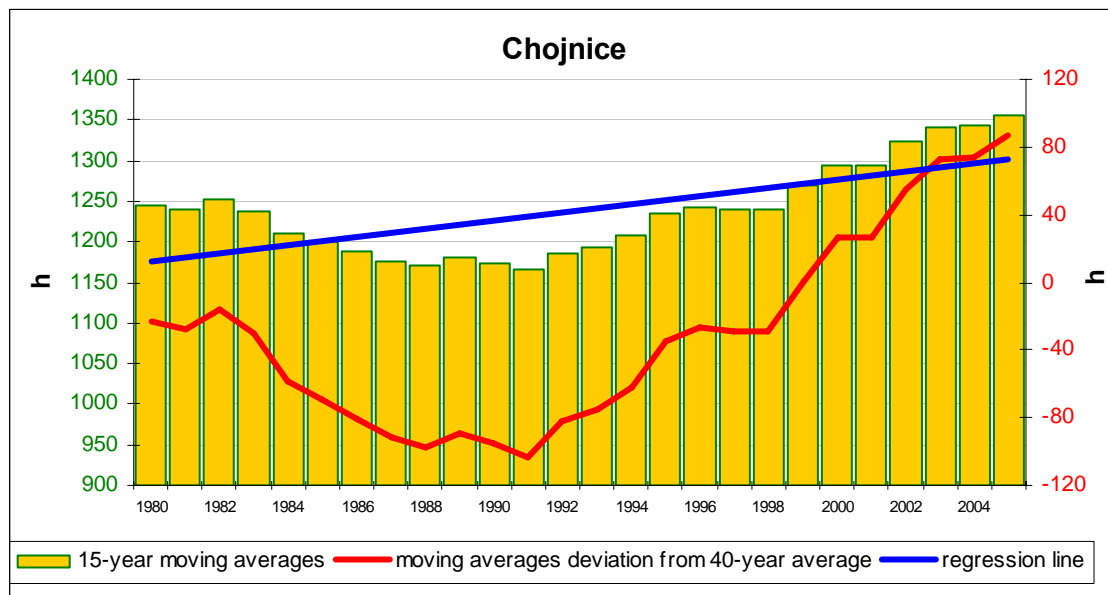
Sunshine hours fluctuations were similar for the majority of stations. Moving average maxima occurred in the first 20-year period, especially at its beginning. The maxima were recorded at the end of the second 20-year period.

Figure 20. Periods with the maximum and minimum values of mean 15-year sunshine hours during vegetative season



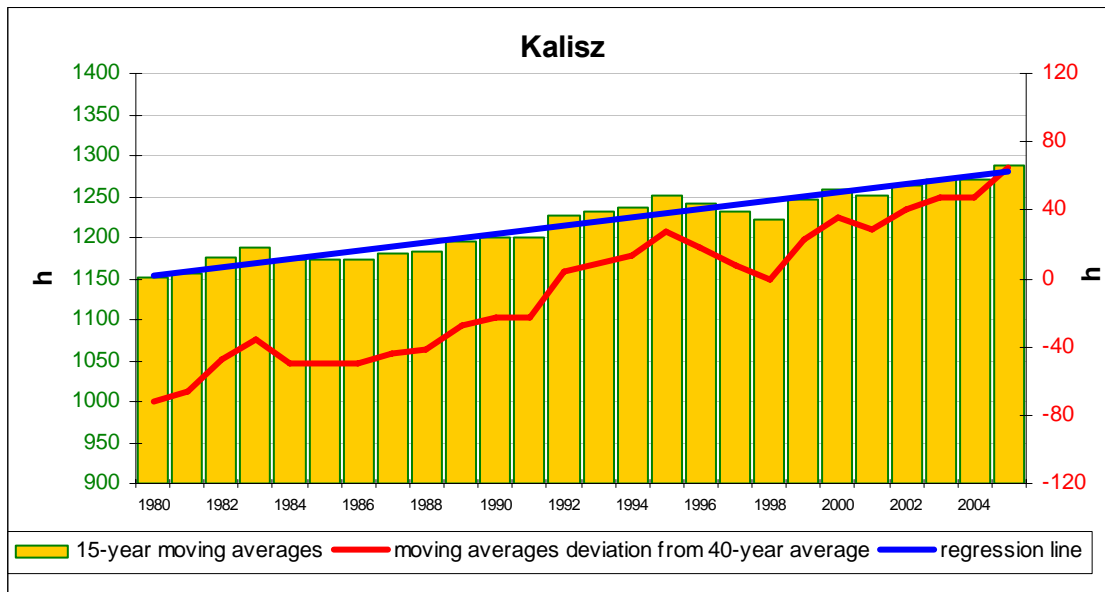
60% of the analyzed stations recorded decrease of sunshine hours in the first 20-year period and a sharp increase in the second period.

Figure 21. Sunshine hours fluctuations in 1966-2005. Chojnice synoptic station. 15-year average 1966-1980 is shown by 1980 bar and etc.



30% of stations recorded a small increase of sunshine hours already in the first two decades.

Figure 22. Sunshine hours fluctuations in 1966-2005. Kalisz synoptic station.
15-year average 1966-1980 is shown by 1980 bar and etc.



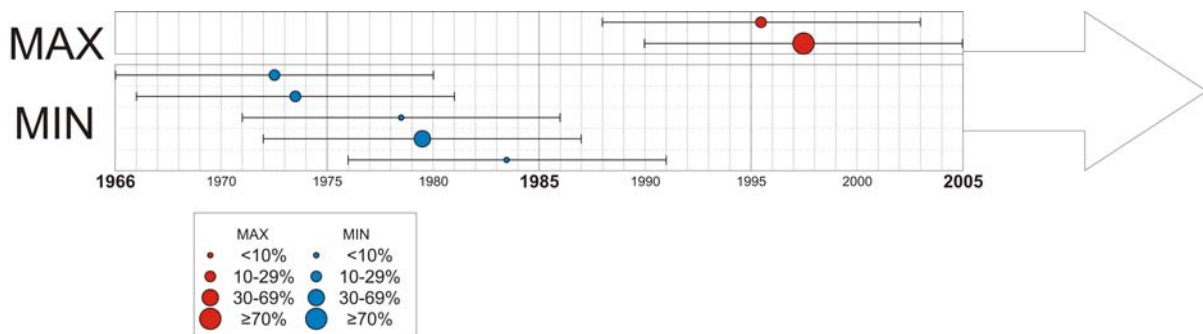
The second 20-year period, especially in the last few years, was characterized by the increased number of sunshine hours in all stations.

Differences between the maximum and minimum values of 15-year mean values were statistically significant at the level of $\alpha=0.05$ at 90% of stations and at the level of $\alpha=0.10$ at the remaining stations.

Evaporation

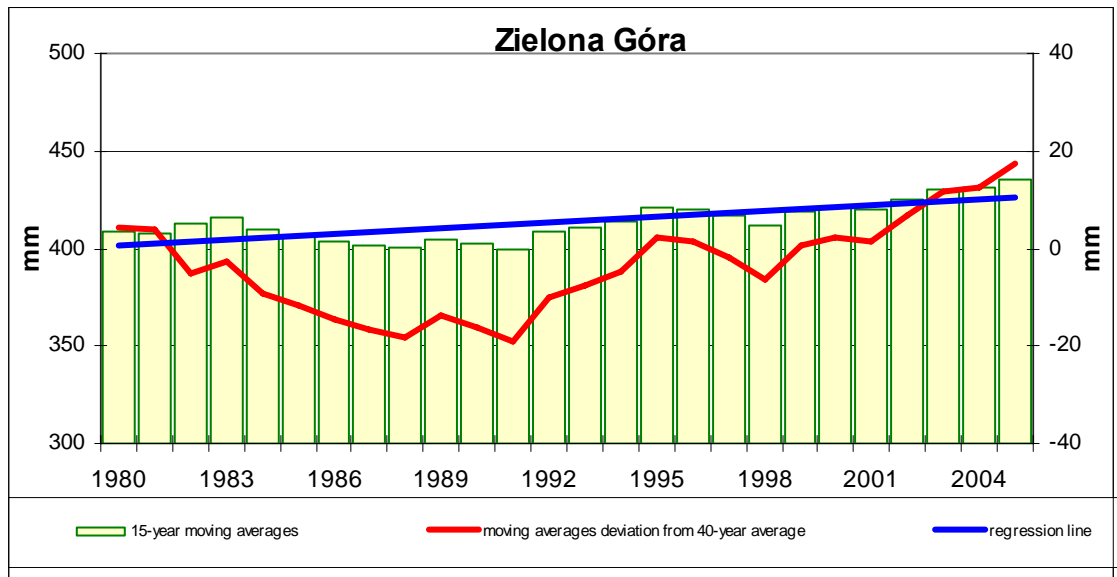
Fluctuation run of evaporation totals was similar for the majority of stations. Moving average minima occurred in the first 20-year period and maxima at the end of the second 20-year period.

Figure 23. Periods with the maximum and minimum values of mean 15-year evaporation totals during vegetative season



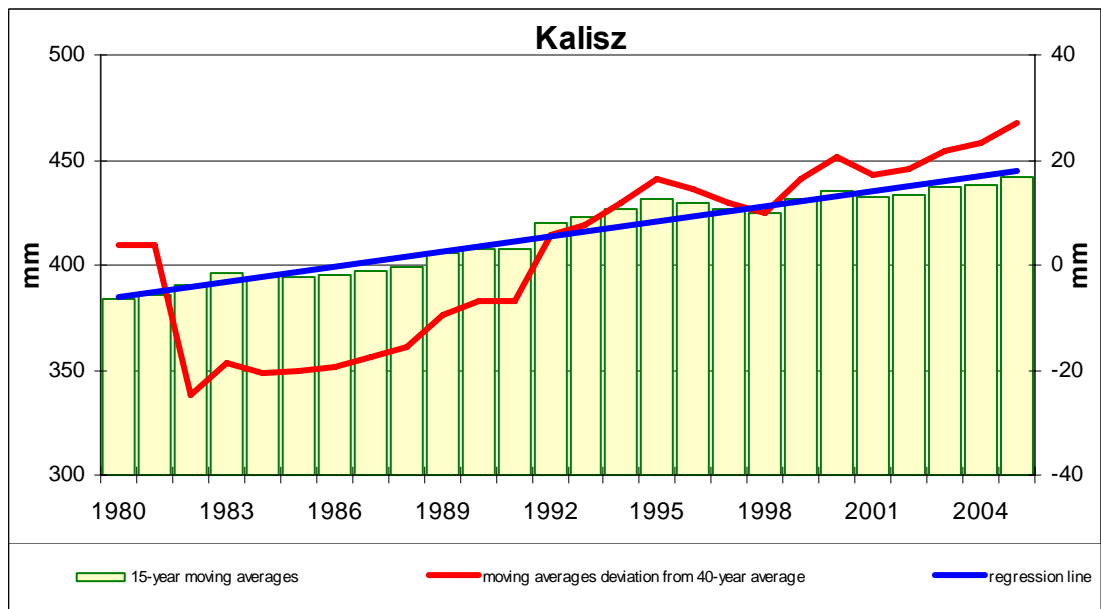
In case of 71% of stations small decrease of evaporation totals of the first 20-year period was followed by their increase in the second 20-year period.

Figure 24. Evaporation totals fluctuations in 1966-2005. Zielona Góra synoptic station.
 15-year average 1966-1980 is shown by 1980 bar and etc.



All the remaining stations recorded a steady increase of evaporation total values throughout the entire 40-year period. This increase was weaker in the first two decades and stronger in the second period.

Figure 25. Evaporation totals fluctuations in 1966-2005. Kalisz synoptic station.
 15-year average 1966-1980 is shown by 1980 bar and etc.

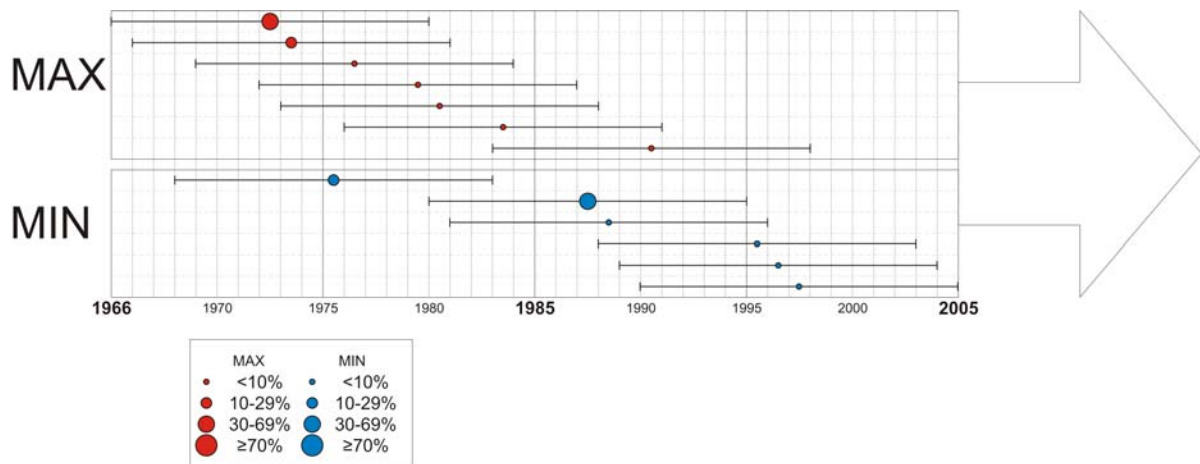


Differences between the maximum and minimum values of 15-year mean values were statistically significant at the level of $\alpha=0.05$ at 86% of stations and at the level of $\alpha=0.10$ at the remaining stations.

Climatic Water Balance (CWB)

Fluctuations of CWB were similar for all stations.

Figure 26. Periods with the maximum and minimum values of mean 15-year Climatic Water Balance during vegetative season



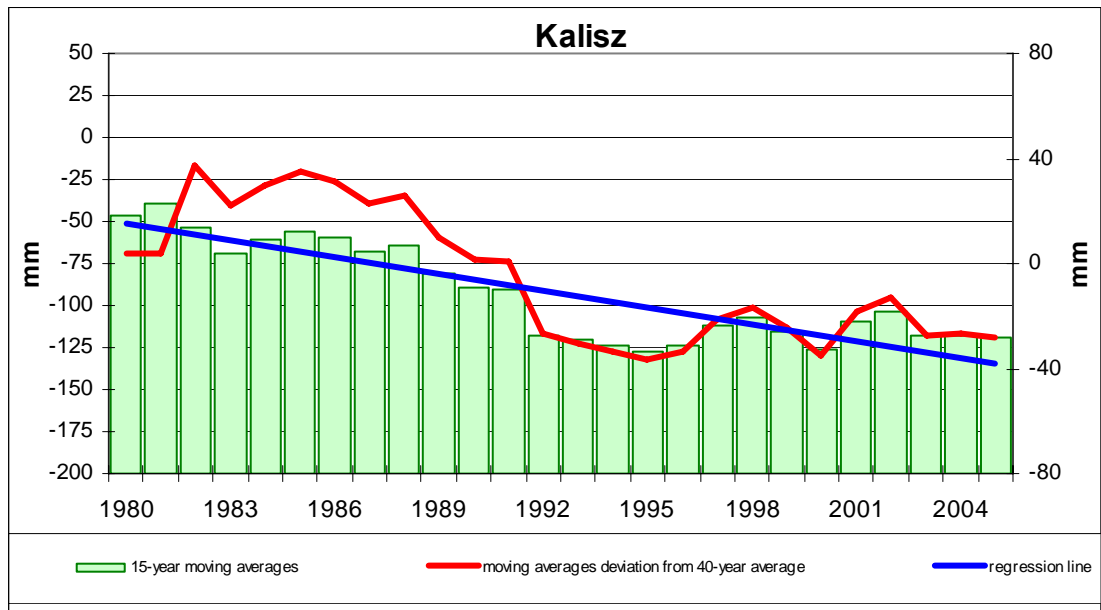
Moving average maxima occurred in the first 20-year period, especially at its beginning. The minima were recorded in the second 20-year period, also at its beginning.

71% of all analyzed stations recorded a decrease of CWB values during the first 20-year period with the minimum occurring at the beginning of the second 20-year period. It was followed by a temporary increase of CWB values which then started to decrease again.

In the last years of the second 20-year period, all stations recorded a decrease of CWB values.

Differences between the maximum and minimum values of 15-year mean values were statistically significant at the level of $\alpha=0.05$ at almost 30% of stations and $\alpha=0.10$ at the 60% of stations.

Figure 27. Climatic Water Balance fluctuations in 1966-2005. Kalisz synoptic station.
15-year average 1966-1980 is shown by 1980 bar and etc.



6. Conclusions

Indices characterizing water supply:

- atmospheric precipitation totals [mm]
- number of days with precipitation of ≥ 3 mm
- number of days with precipitation of ≥ 20 mm

- fluctuation runs of each particular index were not the same for all stations;
- in the majority of cases (55-70% of stations) the first 20-year period was characterized by a decreasing trend, and in the second 20-year period by an increasing trend of the analyzed indices. The remaining stations noted an increase of precipitation totals also in the first 20-year period;
- despite the general increasing trend in this group of indices, the last years of the second 20-year period were characterized by a decrease of atmospheric precipitation totals (50% of all stations) and a decrease of number of days with precipitation of ≥ 3 mm (71% of stations);
- the differences between the extreme values of moving averages were relatively small. The differences were most visible for precipitation totals (statistical significance level of $\alpha=0.05$ for 1/3 of the stations, and $\alpha=0.10$ for the remaining 2/3 of stations).

Indices determining water losses:

- mean air temperature [$^{\circ}\text{C}$]
- number of hot days ($T_{\max} \geq 25^{\circ}\text{C}$)
- number of extremely hot days ($T_{\max} \geq 30^{\circ}\text{C}$)
- sunshine hours [h]
- evaporation [mm]

- fluctuation runs of particular indices were similar or identical for all stations;
- the group of thermal parameters (the first three in this group) was characterized by small fluctuations and weak decreasing tendency in the first 20-year period and a strong increase of their values in the second period;
- values of evaporation and number of sunshine hours showed decreasing trend (60-70% of stations) in the first period and they increased in the second 20-year period. In case

- of 30% of stations, there was a weak increase of values of these parameters already in the first period;
- all indices contributing to water losses showed increasing trends throughout the entire second 20-year period;
 - differences of the extreme values of moving averages for this group of indices were high - they were statistically significant at the level of $\alpha=0.05$ in case of 86-93% of all stations (the minima occurred in the first two decades, the maxima in the second).

Climactic water balance (CWB)

- the CWB values are the outcome of elements that determine water supply available for plants and elements that cause water losses;
- fluctuations of this index were similar in case of the majority of stations;
- the majority of stations (70%) experienced a decrease of CWB values in the first 20-year period. During the second period, after a temporary increase, the CWB values dropped again. In the last years, all stations showed a decreasing trend of CWB;
- differences between the extreme values of moving averages were not very high (only 1/3 of stations had statistically significant difference values of $\alpha=0.05$).

Final remarks on water volume available for plants based on the results of fluctuation analysis of selected agrometeorological indices:

- in the first 20-year period water supply decreased due to decreasing totals of atmospheric precipitation;
- in the second 20-year period, the conditions did not improve. Initially, climatic water balance showed an increased tendency caused probably by higher precipitation. This short-lived improvement, however, was followed by a decreasing water supply;
- the major cause of such conditions in the last years was the evidently increasing trend of air temperature and sunshine duration values that contributed to higher evaporation while there was no water recharge from simultaneously decreasing atmospheric precipitation totals;
- analysis of data collected in Poznań station located in the central part of the studied area for the period of 2006-2009 indicated that the trends of the analyzed indices continue to develop in the directions determined at the beginning of the present decade (2001-2010).

Direction of changes of the basic agroclimatic indices in the Wielkopolska region indicates that water deficit during vegetative period will continue to worsen.